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Author: A. Zalewska, W. Pytel, M. Chorowski, S. Cygan, S. Hanzel, K. Januszewska, Jan Kisiel, Tomasz Szeglowski i in.

Citation style: Zalewska A., Pytel W., Chorowski M., Cygan S., Hanzel S., Januszewska K., Kisiel Jan, Szeglowski Tomasz i in. (2010). LAGUNA in Polkowice-Sieroszowice mine in Poland. "Acta Physica Polonica B" (Vol. 41, no. 7 (2010), s. 1803-1812).

Vol. 41 (2010) ACTA PHYSICA POLONICA B No 7

LAGUNA IN POLKOWICE–SIEROSZOWICE MINE IN POLAND*

A. Zalewska[d], W. Pytel[a], M. Chorowski[h], S. Cygan[a]
S. Hanzel[a], K. Januszewska[c], L. Jaroń[b], J. Kisiel[f], L. Lankof[c]
A. Markiewicz[a], P. Markowski[b], P. Martuszka[a], M. Raczyński[a]
Z. Sadecki[a], J. Sobczyk[g], R. Sulej[e], M. Szarska[d], J. Ślizowski[c]
T. Szeglowski[f], K. Urbańczyk[c]

[a]KGHM CUPRUM CBR, Wrocław, Poland
[b]Polkowice–Sieroszowice mine, division of KGHM Polska Miedź S.A. Kaźmierzów, Poland
[c]Mineral and Energy Economy Research Institute PAN, Kraków, Poland
[d]The H. Niewodniczański Institute of Nuclear Physics PAN, Kraków, Poland
[e]The A. Sołtan Institute for Nuclear Studies, Warszawa, Poland
[f]University of Silesia, Katowice, Poland
[g]Wrocław University, Wrocław, Poland
[h]Wrocław University of Technology, Wrocław, Poland

(Received July 5, 2010)

The Polkowice–Sieroszowice mine in one of the seven candidates for the future pan-European underground laboratory studied in the framework of the LAGUNA project. We review the evidence that from the point of view of geology, long-term plans for the mine and existing infrastructure, and support of the authorities this is a perfect place to host the 100 kton liquid argon detector GLACIER.

PACS numbers: 01.52.+r, 14.60.Lm, 13.30.–a

1. Introduction

Four decades of measurements of neutrinos from the Sun and the observation of neutrinos from the Supernova explosion in 1987 caused that it became clear that low energy astrophysical neutrinos are important messengers for stellar processes. The subsequent discovery of neutrino oscillations in experiments studying neutrinos from different sources (atmosphere, accelerators, Sun and reactors) significantly strengthened the opinion about

* Presented at the Cracow Epiphany Conference on Physics in Underground Laboratories and Its Connection with LHC, Cracow, Poland, January 5–8, 2010.

the importance of neutrino physics. Another big, but still open question, concerns the proton decay, predicted by Grand Unification Theories aiming at the unification of fundamental forces in Nature.

Achieving further significant progress in neutrino studies and searches for proton decay requires huge detectors on the 100–1000 ktons scale, *i.e.* by one to two orders of magnitude larger than the existing ones. Deeper understanding of neutrino properties, in particular of CP violation, if any, could be obtained in studies with intense accelerator neutrino beams. In Europe, the neutrino beams have been and could be further produced at CERN. More about the physics justification for the LAGUNA project can be found in [1].

At present, there is no single infrastructure in the world which could host the future huge detectors. The LAGUNA project [2], in agreement with the ApPEC roadmap, looks for the location in Europe for three types of detectors: GLACIER filled with 100 ktons of liquid argon, LENA filled with 50 ktons of liquid scintillator and MEMPHYS filled with several hundred ktons of water. The choice should take into account, in particular, the local geological conditions, the existing infrastructure and its availability to the project over a period of 40 years, various sources of background as well as the distance from CERN.

One of the seven possible locations of the future LAGUNA laboratory is the Polkowice–Sieroszowice mine in Poland, belonging to the KGHM Polska Miedź S.A. holding of copper mines and metallurgic plants. The prefeasibility study for this location to host the GLACIER detector was performed in the years 2004–2006, *i.e.* before the LAGUNA project was started. It contained two elements: measurements of the background due to natural radioactivity of surrounding rocks and geomechanical simulations of the excavation of a huge salt cavern.

The measurements of natural radioactivity in the Polkowice–Sieroszowice mine consisted of alpha and gamma spectrometric measurements on salt and anhydrite samples, of long-term integrated dose measurements with thermoluminescent detectors, of *in situ* gamma measurements using Ge detector and of radon content measurements of air. The results of all measurements showed that the level of natural radioactivity is exceptionally low. Details can be found in [3].

Two independent geomechanical analyses have been performed [4, 5]. In both a 30 year period of the cavern exploitation was assumed. According to the results of these preliminary studies the salt cavern should be stable down to the depth of 750 m, at larger depths the cavern instability could not be excluded, however, destabilisation of the waterproof anhydrite layers was excluded. After 30 years of exploitation, a horizontal squeezing by up to 1.5 m, due to the salt viscous creep, was foreseen.

The thorough feasibility studies have been performed for SUNLAB (Sieroszowice UNderground LABoratory) within the LAGUNA project and are outlined in the present paper. It appears that the GLACIER detector fits perfectly to the local conditions, the LENA detector could be constructed, but in horizontal position, while the MEMPHYS detector rises serious problems.

2. General information

The Polkowice–Sieroszowice mine (51°33′ 21" N–16°2′ 30" E) is a copper mine (with additions of other metals and salt extraction as well) located in Kaźmierzów, district Polkowice, province Lower Silesia in south-western Poland (see map in Fig. 1). The mine is placed at the national north–south road number 3, about 40 km from the motor way A4 crossing southern Poland in the east–west direction. At the western boarder of Poland A4 is connected to the German motor ways. The international airport in Wrocław is at a distance of about 90 km. The nearest sea-port is at the Baltic sea in Szczecin (268 km using the national road nr 3 or by railway).

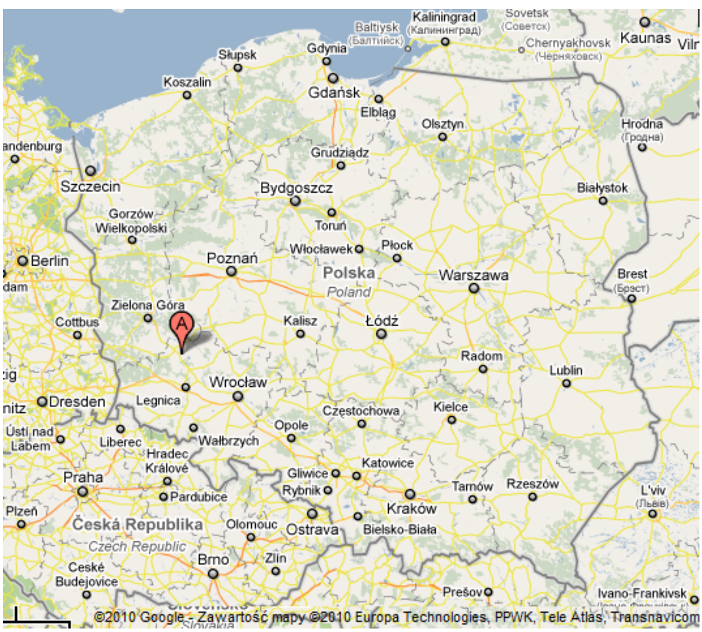

Fig. 1. Location of the Polkowice–Sieroszowice mine on the map of Poland.

There are three towns, Polkowice, Lubin and Głogów, at a short distance from the Polkowice–Sieroszowice mine. Polkowice is located 4 km to the south, counts *circa* 23000 inhabitants and has three hotels and three hostels.

Lubin — 20 km to the south, counts *circa* 80000 inhabitants, hosts the headquarters of KGHM Polska Miedź S.A., several hotels, a large hospital, a railway station and a local airport. Głogów — 17 km to the north, counts *circa* 70000 inhabitants, hosts several hotels and a large hospital. Apart from that, Wrocław, the capital of Lower Silesia is located at a distance of about 90 km SE from the mine. The town counts *circa* 630000 habitants, has a big railway station, an international airport, highly specialised hospitals, several universities and other high education and research institutions and a rich cultural life.

The distance of the Polkowice–Sieroszowice mine from CERN is 950 km for neutrinos and about 1200 km for road transport. The mine has a relatively low background due to antineutrinos from nuclear power stations. At present, the closest reactors are located at a distance of about 300 km, in Dokovany and Temelin in the Czech Republic.

3. Political and legal issues

The Polkowice–Sieroszowice mine (see Fig. 2) belongs to the KGHM Polska Miedź S.A. holding of copper mines and metallurgic plants in south-western Poland. KGHM is a joint-stock company with the State Treasury being a main shareholder. In agreement with Polish law the state is owner of all underground ores. The Polkowice–Sieroszowice mine has the permits for excavation in the area where the location for the LAGUNA infrastructure is proposed. However, any underground activity, which is not directly related to mining must be accepted by the Chief National Geologist from the Ministry of Environment. Legal problems directly related to excavation works are regulated by the Polish Mining Law and specific rules of the mine.

The only research activity performed up to now in the Polkowice–Sieroszowice mine concerned the measurements of the natural radioactivity, described in [3]. Further work is planned in two steps. The construction of the initial laboratory SUNLAB1 should start this year. SUNLAB2 — the big pan-European underground laboratory — is studied within the LAGUNA project. Therefore, SUNLAB2 depends on the outcome of LAGUNA. SUNLAB has strong support in Poland at various levels. At the governmental level the Ministry of Science and Higher Education recently put SUNLAB on the roadmap among the most interesting future research infrastructures in Poland. There is also a strong local support from the authorities of the Lower Silesia region. The application for the initial laboratory SUNLAB1 was signed by twelve higher education and/or research institutions in Poland. In particular, strong support is offered by the academic and scientific institutions in Wrocław, which is one of the most important academic centres in Poland.

Fig. 2. Photo of the Polkowice–Sieroszowice surface buildings.

The KGHM Management Board and the management of the Polkowice–Sieroszowice mine are very supportive for SUNLAB. The agreement (MoU) between KGHM and the Ministry of Science and Higher Education for SUNLAB1 has been drafted and is subject of negotiations. Once accepted, the procedure could then be applied to SUNLAB2 — the laboratory hosting the LAGUNA detector.

4. Characterisation of the mine

KGHM Polska Miedź S.A. is often referred to as the European copper giant. On the world scale it is among the ten top producers of copper. For example, in 2008 11×10^6 tons of ore were extracted. It is also the second biggest producer of silver. There are over 4000 employees in the Polkowice–Sieroszowice mine, which is one of the three active mines of the holding. The whole KGHM holding has over 18000 employees. The Polkowice–Sieroszowice mine itself currently operates in three mining regions with a total surface area of about 178 km^2. It has been under continuous operation for almost 30 years. Consequently, there is much experience in excavation work, a team of highly qualified mining engineers and also equipment for large scale underground work.

The mine infrastructure includes a number of large access shafts (up to 7.5 m in diameter), an extended network of underground roads, a very efficient ventilation system, machines for fully mechanised extraction work and cars for the underground transport.

According to the mine development strategy the further lifetime of the mine is being estimated as no less than 40 years. This is essential, because the cost of running the laboratory would be much higher if the mine did not take care of the infrastructure. At present, the Polkowice–Sieroszowice mine is developing the system for mining ore at larger depths, up to 1500 m below the surface.

5. Geological conditions

The Polkowice–Sieroszowice mine is operating within tectonically stable and good quality hard rock consisting of dolomites and anhydrites, and locally of rock-salt. The geological structure within the mine is known very well because of the long lasting copper exploitation in this area. Several exploration boreholes have been drilled from the surface and the rock samples have been studied in the KGHM specialised laboratories.

Rock quality is characterised by a number of parameters. The most important parameters for the Polkowice–Sieroszowice anhydrite are as follows:

- Strength:
  - intact rock strength: tensile strength $C_0 = 124.1$ MPa, unconfined compressive strength $T_0 = 7.6$ MPa, Geological Strength Index GSI = 70–80; rock of very good quality with no cracks and weakness zones,
  - rock mass strength (including scale factor): $C_0 = 27.6$ MPa, $T_0 = 0.4$ Mpa,
  - cohesion $c = 6.3$ Mpa, angle of internal friction $\phi = 37.6°$ (initial), $c = 0.6$ Mpa, $\phi = 20.8°$ (residual); both values include a scale factor.
- Stress: *in situ* stress characteristics before excavation: vertical component $\sigma_{\mathrm{vv}} = 14.8$ MPa, smallest horizontal component $\sigma_{\mathrm{hh}} = 7.8$ MPa, largest horizontal component $\sigma_{\mathrm{HH}} = 24.4$ MPa directed at an angle of 301° clockwise from the north.
- Combined stress around cavern after excavation: $\sigma_{xx} = 1$–30 MPa, $\sigma_{yy} = 1$–30 MPa, $\sigma_{zz} = 0$–48 MPa;
- Rock behaviour: elastic-plastic with strain softening;
- Vertical deformations: $w_z =$ from -0.078 m (vault) to 0.244 m (floor), horizontal deformations are smaller.

The temperature at the depth of 600 metres is $+28°$. The temperature increases with the depth by about $1.5°$ per 100 metres. The anhydrite rock in the Polkowice–Sieroszowice mine is dry.

Polish territory (except mountains in the south) belongs to non-seismic regions, so earthquakes are rare and weak. In the Polkowice–Sieroszowice mine micro-seismic rockbursts are present due to the ore exploitation, but they are continuously measured by the mine seismic monitoring system.

6. Geomechanical analyses

Two independent geomechanical analyses were made by KGHM CUPRUM CBR and by IGSMiE PAN and provided consistent results. Two detectors have been seriously considered for SUNLAB: GLACIER and LENA. The MEMPHYS detector was not taken into account, because it would require location in mixed rock, which according to existing experience is considered too risky for an excavation of this size. In addition to geological issues, in the case of tank failure, this would increase a potential risk to spoil surrounding rocks by water, resulting in anhydrite swelling with associated strength decrement.

Geomechanical studies for GLACIER have been performed for the following four locations:

- cavern in salt rock at the depth of 983 m below surface (b.s.),
- cavern in lower anhydrite at the depth of 1112 m b.s.,
- cavern in upper anhydrite at the depth of 617 m b.s.,
- cavern in upper anhydrite at the depth of 636 m b.s.

The GLACIER cavern at the depth of 636 m b.s. (1400 m water equivalent) was found to be the best, so the full infrastructure and cost evaluations were performed for this site. It is located in a 115 m thick, homogeneous anhydrite layer in a part of the mine where a detailed geological survey has been done and the copper exploitation has almost finished.

The geomechanical studies for LENA detector have been performed for a cavern located in a lower stratum, 90 m thick, anhydrite rock at the depth of 1370 m b.s. (3300 m.w.e.). The cavern appears feasible, but only for a horizontal design. The horizontal tank orientation would create a lot of technical support problems, which are not present in the case of LENA oriented vertically.

7. Engineering evaluation

Figure 3 illustrates the concept of the LAGUNA laboratory for the GLACIER detector in the Polkowice–Sieroszowice mine, including the main detector cavern, service caverns, access ramps and galleries as well as emergency caverns.

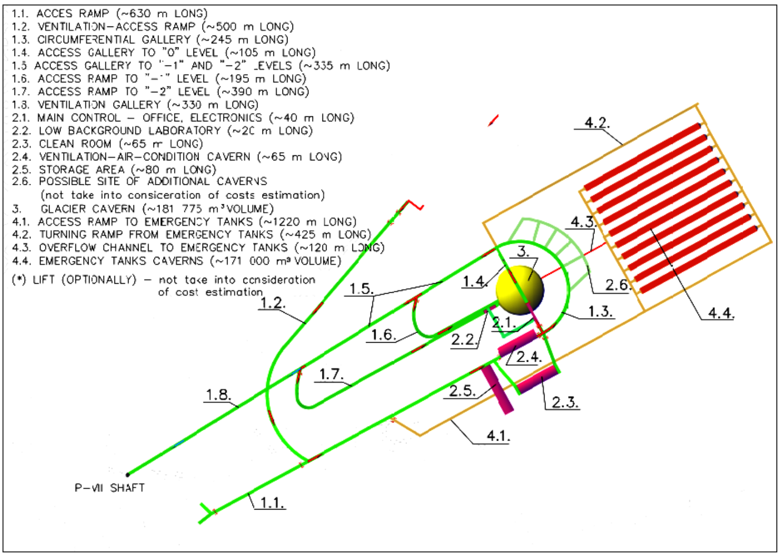

Fig. 3. Scheme of the LAGUNA laboratory for the GLACIER detector.

Issues related to the excavation include:

- Excavation strategy assumes very little disturbance to the anhydrite rock surrounding the main detector cavern. Therefore a carefully controlled blasting method of rock excavation is recommended. A machine excavation technique is also possible. The top heading and bench/ramp method of excavation is foreseen.
- Types of reinforcements: Ground support will consist of two sets of rock bolts: resined threadbar anchors of the length of 25 m at about 1.5 m spacing, and resined polyester-glass bolts of the length of 6 m at about 1.5 m spacing, stainless steel wire mesh and organic-mineral membrane spraying.
- Rock disposal: The amount of rock due to the excavation of the LAGUNA laboratory complex will be maximally of the order of 10% of the annual removal of copper ores in the KGHM mines. Thus it does not pose any problem. Most likely it will be re-used underground to fill empty caverns on the copper level. Alternatively, it could be stored on the surface storage areas.

- The expected environmental impact of the LAGUNA project is much smaller than that related to the normal operation of the Polkowice–Sieroszowice mine. The environmental issues are well understood and are even part of the firm strategy and mission.
- Supply routes underground: via about 1700 m new gallery from the shaft P-VII.
- Interference with host activities: Minimal, because copper excavation is almost finished in the area close to the GLACIER location and the laboratory will have its own underground access tunnels and galleries.

Issues related to the detector tank construction underground are elaborated by experts from Technodyne Ltd. The information relevant to the tank construction in the Polkowice–Sieroszowice mine has been transferred to them.

The LAGUNA laboratory will be located close to the large shaft P-VII (7.5 m of diameter) which will be almost entirely at its disposal. Ventilation of the laboratory will be connected to the existing mine ventilation system. There is enough space on the surface in the vicinity of shaft P-VII to construct the surface laboratory, workshop for the tank pre-assembly and storage areas. The shaft P-VII surface building can also be used by LAGUNA.

The mine has its own railway yard at a distance of 3.5 km from the P-VII shaft, with very good external railway connections, *e.g.* to the harbour in Szczecin. This can be used for transport of the detector construction elements. The scheme of transport between the railway yard and the main detector cavern underground is illustrated in Fig. 4. The liquid argon can be delivered using the road transport (about 12 kton/year, *i.e.* 20% of the total Polish production, could be delivered to LAGUNA). The argon delivery underground needs to be elaborated.

The LAGUNA site is located in an out-of-the-way place, there will be no interference with mine transport and communication roads. No blasting will happen in close vicinity of the site, ore transport is directed to shafts different than P-VII and double circuits will protect the laboratory against power disruptions.

8. Conclusions

The Polkowice–Sieroszowice mine is operating within tectonically stable and good quality hard rock consisting of dolomites and anhydrites, and locally of rock-salt. Anhydrite layers provide excellent conditions for locating the LAGUNA laboratory. The mine infrastructure includes a number of large access shafts (up to 7.5 m in diameter), an extended network of underground roads, ventilation system, machines for fully mechanised extraction

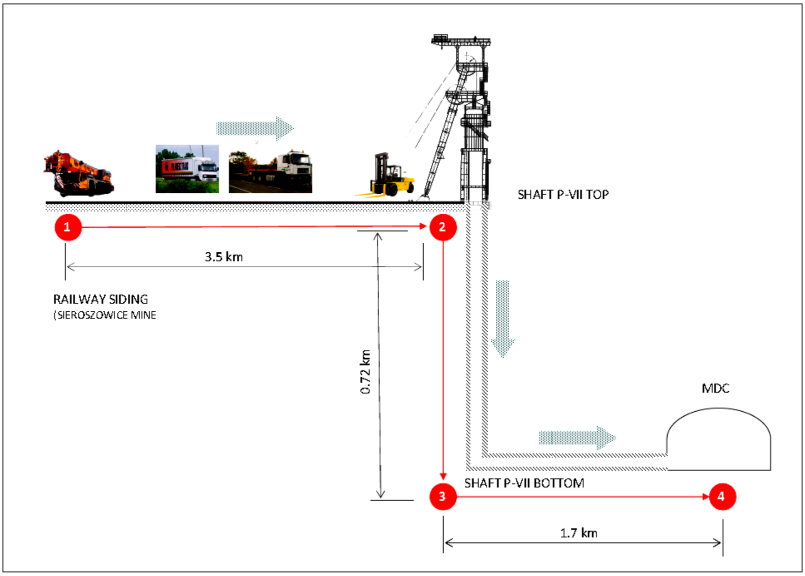

Fig. 4. Transport scheme between the mine railway yard and the main detector cavern.

work and cars for underground transport. The Polkowice–Sieroszowice mine is located in an urbanised area with good communication and all kinds of available services. The mine is ideally suited to host the LAGUNA laboratory for the GLACIER detector located at 636 m b.s. in a homogeneous anhydrite block with no copper ore layer below.

The LAGUNA design study is financed by the FP7 Research Infrastructure "Design Studies", Grant Agreement No. 212343 FP7-INFRA-2007-1. The Polish groups in LAGUNA acknowledge also the support of the Ministry of Science and Higher Education.

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